Model-based Hyperspectral Exploitation Algorithm Development

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LONG-TERM GOALS

Hyperspectral data is becoming a critical tool for military planners. The capture of fine spectral information enables the generation of information products which could not be produced using traditional imaging means. The challenge facing the insertion of hyperspectral technology, as an operational capability, is with conversion of the raw sensor data into a useful information product that is accurate and reliable. Traditional approaches for processing hyperspectral data have largely focused on the use of statistical tools to process a hypercube, with little regard for other data that may describe the physical phenomena under which the data was collected. The long-term goal of this project is to develop a new generation of hyperspectral processing algorithms that take advantage of underlying physics of a scene while utilizing statistical processing techniques to generate valuable information products.

OBJECTIVES

The objectives of this project are to develop hyperspectral analysis tools that incorporate physics-based processing in the following application areas:
- Water quality and biological activity (littoral zone)
- Material classification and identification
- Atmospheric parameter retrieval/correction
- Gaseous effluent detection and quantification

The output of this project will be processed data sets and, in some cases, information products that demonstrate what is feasible.

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14. ABSTRACT
Hyperspectral data is becoming a critical tool for military planners. The capture of fine spectral information enables the generation of information products which could not be produced using traditional imaging means. The challenge facing the insertion of hyperspectral technology, as an operational capability, is with conversion of the raw sensor data into a useful information product that is accurate and reliable. Traditional approaches for processing hyperspectral data have largely focused on the use of statistical tools to process a hypercube, with little regard for other data that may describe the physical phenomena under which the data was collected. The long-term goal of this project is to develop a new generation of hyperspectral processing algorithms that take advantage of underlying physics of a scene while utilizing statistical processing techniques to generate valuable information products.

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APPROACH

Traditional approaches for processing hyperspectral data have largely focused on the use of statistical tools to process a hypercube, with little regard for other data that may describe the physical phenomena under which the data was collected. The RIT MURI research team has been developing physics-based models that enable the environment, under which remotely sensed data is collected, to be better described (Schott 2000). Under this MURI project, we are using these physics-based models, along with statistical processing techniques to evaluate the effectiveness of this approach for processing hyperspectral data sets.

Key individuals that make up the RIT MURI research team include:
- Dr. John Schott [RIT] - Principal Investigator overseeing the project research activities.
- Dr. Glenn Healey [UC, Irvine] – Developing invariant algorithm approaches and specific applications for material identification.
- Dr. William Philpot [Cornell University] – Developing techniques for modeling the inherent optical properties of water and supporting the littoral zone modeling.

WORK COMPLETED

The RIT MURI team has just completed its second of research activity. The first year's efforts focused on definition of the underlying phenomenology and evaluation of initial approaches to physics based algorithms. In particular model matching techniques were tested for water constituent concentration retrieval and an initial subpixel material identification approach was implemented. The second year's efforts have focused on: designing and testing algorithms to take advantage of physics based models that were identified and proved appropriate during the first year, developing new or improved models where required and developing new ways to interface algorithmic tools to physical models.

RESULTS

The following is a summary of key results by application area:
- Water quality and biological activity (littoral zone). This year's effort focused on refinement of a method to use on in-water radiative transfer code, Hydrolite and on atmospheric propagation code (Modtran) to generate remotely sensed spectral reflectance as a function of the primary coloring agents. These concentrations are then recovered on a per pixel basis using a model matching and inversion routine (cf Raqueno et al 2001).
- open water model-based-model-match algorithm implemented and tested to determine in-water constituents from LEO-15 data set.
- identified and began development of a 3D in-water radiative transfer modeling approach for shallow water and complex water environments (Photon Mapping).
- Initiated development of in-water and air-water interface models for generation of radiance and apparent reflectance in complex water environments.
- Continued development and implementation of atmospheric correction for shallow water environments.
- Conducted demonstration of relationship between observed Inherent Optical Properties (IOPs) and observed spectra.
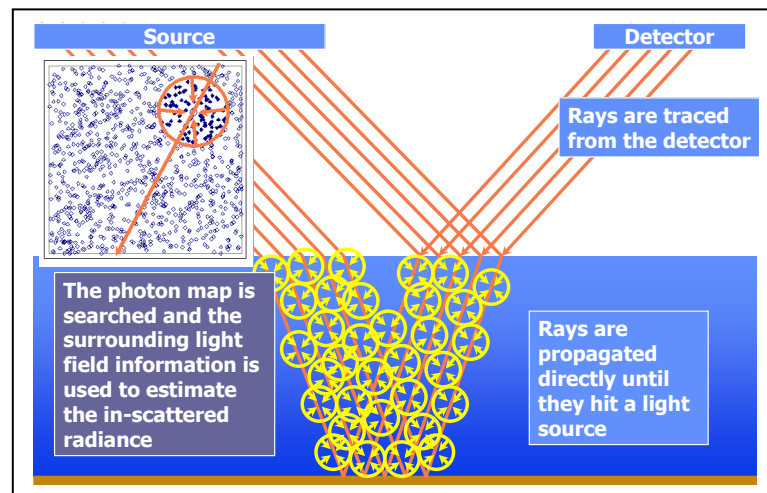
Figure 1 – Photon Mapping
[Photon Mapping is being Developed as a Technique for 3 Dimensional
Modeling in Shallow Water Environments]

- Designed and conducted a concentrated, localized water field collect at Conesus Lake designed to provide data for model validation.
- Software development activities
- Interactive software tool to investigate the behavior of the scattering phase function
- Particle IOP simulator: computes particle scattering codes for IOPs (a, b, bb ratio, phase function, cumulative scattering).
- Phytoplankton IOPs
- Optical modeling of a phytoplankton particle (modified OOPS)
- Phytoplankton culture system in constant operation (spectrophotometer with integrating chamber, cell counting, cell shape analysis, pigment analysis)
- Potential approach to measure backscatter parameters needed for input to radiative transfer models
- Inclusion of several major suspended mineral particles in the radiative transfer simulation measurement of a, b spectra.
- Atmospheric parameter retrieval and correction
- initial TIR atmospheric characterization algorithm implemented to yield per pixel atmospheric profiles, temperature and water vapor, and surface temperature.
- Demonstrated the ability of Canonical Correlation Regression Analysis (CCRA) to perform spatial first order sounding retrieval of temperature and water vapor profiles (support for radar ducting analysis requires evaluation of vertical resolution)
- Initial demonstration of ability to retrieve spectral emissivity (alpha residual) using CCRA inversion of MODTRAN.
- ISAC identified as a data driven approach for apparent emissivity retrieval with very low spectral noise, but significant bias.
- Studied potential for the merger of ISAC and CCRA.
- Studied methods to model variable light field on modeled and observed reflectances.
- Gaseous effluent detection and quantification

- stack plume model implemented with enhanced in-plume radiative transfer
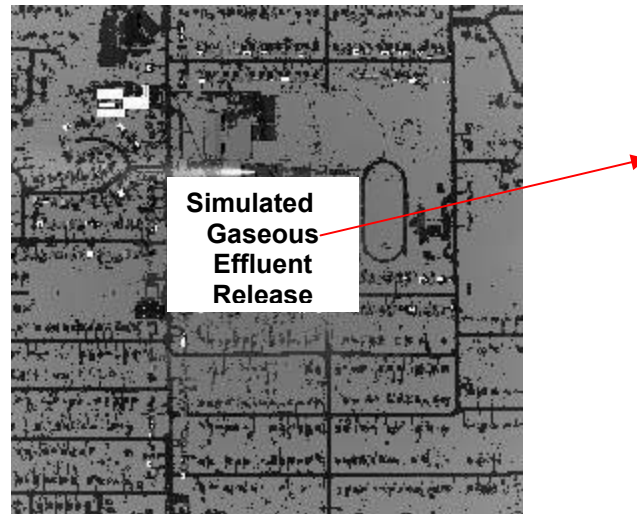- initial gas detection algorithm approach identified

Figure 2 – DIRSIG Synthetic IR Image
[The DIRSIG physics-based model is being used to develop and test detection and quantification algorithms over a variety of environmental conditions]

- Established a real and synthetic test environment for evaluation of detection and identification algorithms
- Implemented several initial detection algorithms and have initiated testing on SEBASS data set.
- Defined and implemented a model-based invariant algorithm for plume detection and identification.
- Defined enhanced regression approach to overcome limits of nominal regression approach (e.g. improved basis vectors and step-wise alternative)
- Material classification and identification
- Subpixel invariant algorithm developed and initial results promising (cf Lee 2002).
- Implemented and refined a sub-pixel target detection approach including improving robustness and automation. Transferred algorithm code to other government/industry Users.
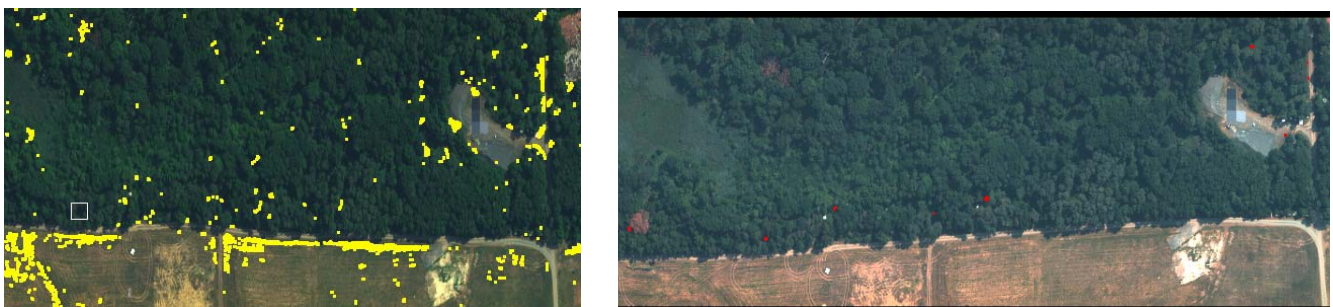

Figure 3 - Application of Target Detection Algorithms Searching for Green Panels
[Image on left demonstrates multiple false alarms using direct spectral matching technique.
Image on right demonstrates accurate detection of concealed panels using Invariant Algorithm]

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- Defined approach to extend sub-pixel invariant technique to concealed and contaminated targets.
- Developed and demonstrated a mothod for the local separation of reflectance and illumination spectra.
- Developed and demonstrated a technique for end-member estimation using independent component analysis.
- Developed and demonstrated opponent feature method for texture classification.
- Developed and demonstrated multi-band correlation method for invariant 3D texture classification.
- Developed and demonstrated invariant subspace method for texture classification.

IMPACT/APPLICATIONS

The RIT MURI Team believes that this research work can have a significant impact in how hyperspectral data is process and how the resulting information products are generated. The invariant algorithm research is already showing promise in reducing false alarms under varying collection conditions. The water modeling activity is showing promise for a more accurate 3D representation of shallow water optical conditions, thus allowing more accurate detection of objects in the water.

TRANSITIONS

The MURI team has identified technology transfer as an important element of this project.
- RIT has a research project with the National Imagery and Mapping Agency that involves the implementation of algorithms into an ENVI software environment. One of the algorithms developed under this program has already been selected for implementation under this NIMA effort.

RELATED PROJECTS

- NIMA University Research Initiative (NURI) – RIT project that involves the implementation of advanced hyperspectral algorithms into an ENVI software environment and then conducting robustness testing to evaluate performance. This project started June 2002.
- Army Research Organization (ARO) Multidisciplinary University Research Initiative (MURI) – RIT is on a research team led by Georgia Institute of Technology to develop multi and hyperspectral processing techniques for tactical sensors (UAV and helicopter platforms). RIT's role will be in the generation of physics-based models using DIRSIG that will be used for algorithm development and testing. This project initiated in October 2002.

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